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U.S. PATENT APPLICATION

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Invention: COMPARING THE POSITION OF SHARED OBJECTS

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SPECIFICATION

FOOTNOTES

Comparing the Position of Shared Objects

Background of the Invention

1. Field of the Invention

5 [0001] The present invention relates to a method of defining and updating data structures equipped with data which is preferably continuous, within a shared computer-generated environment.

2. Description of the Related Art

10 [0002] Methods are known to define and update data structures, also known as objects, within shared computer-generated environments. Said objects are traditionally shared between network connected user terminals over a network such as the Internet, with said sharing usually co-ordinated by one or a plurality of central servers. An example of objects defined and
15 shared within a computer-generated environment is provided by professional and recreational computer-based simulations, wherein users individually control computer-generated vehicles, such as aeroplanes and the like, within a computer-generated battle field defined and updated by one or a plurality of central servers, such that said users can interact with one another by means
20 of their respective vehicles.

[0003] In order for the interaction to be immersive, i.e. provide a user with accurate information for every vehicle within the virtual battlefield, all of the attributes of all of the vehicles, such as their respective position, must be
25 updated on all of the participating user terminals as often as possible, such that any particular user can exercise appropriate control of their vehicle

relatively to the respective states of other vehicles controlled by other users. To achieve this, said servers traditionally broadcast the situation of every vehicle within the battle field to all of the participants by means of packets of data which define a complete instantiation of said every vehicle in said battle field.

[0004] However, it is known that for shared computer-generated environments involving hundreds and potentially thousands of participants, the above prior art is most inappropriate as network bandwidth according to the known art precludes updates of the magnitude required for updating said thousands of participants in a timely fashion, which is of the order of hundreds of milliseconds. Furthermore, said network bandwidth is known to fluctuate importantly in open networks such as the Internet, and thus further constricts the speed at which every user terminal participating in a networked application of the type described above can be updated.

[0005] A known method of overcoming the above limitations was proposed by Sandeep Kishan Singhal's in his dissertation "Effective Remote Modelling in Large Scale Distributed Simulation and Visualisation Environments", dated August 1996, with the disclosure of a position history-based dead reckoning (PHBDR) extrapolation algorithm, by means of the implementation of which only continuous data with which a shared object is equipped, such as positional data, requires updating over the network. The implementation of PHBDR reduces the size of the packets of data broadcasted for updating purposes to all of the participants in a networked computer-generated simulation and thus improves the updating frequency.

However, the implementation of PHBDR according to the prior art still does not preclude the updating of a networked simulation, or other type of similarly immersive networked application, from being disrupted in the case of networks afflicted with important bandwidth fluctuation, such as the Internet.

5 In instances where the bandwidth fluctuates beyond the minimum amount required for PHBDR-based updates according to the prior art, a severe degradation of the updating information known to those skilled in the art as 'packet loss' occurs such that the shared objects present within a computer-generated environment simply cease being updated and the local rendering
10 of said objects becomes inaccurate until such time as said bandwidth returns to an optimal value, thereby affecting users' decision-making in the course of their interactions.

3. Brief Summary of the Invention

15 [0006] According to a first aspect of the present invention, there is provided a computer network configured to define and update data structures within a shared computer-generated environment, comprising a plurality of user-computer terminals having display means, storage means, processing means and network connection means, wherein said storage
20 means stores said data structures and program instructions; said processing means is configurable by said program instructions to perform the steps of equipping a first of said data structures with continuous data at a first of said user-computer terminals; at a second of said user-computer terminals, predicting said continuous data of said first data structure;
25 comparing said predicted continuous data with continuous data of a second of said data structures stored at said second user-computer terminals; and

updating said first data structures at said second user-computer terminal in response to said comparison.

[0007] According to a second aspect of the present invention, there is provided a method of updating data structures within a computer-generated environment shared between users connected via computer terminals connected to a network, wherein a user's computer terminal performs the steps of equipping a data structure with continuous data; predicting said continuous data of said data structure; comparing said predicted continuous data with continuous data of a second data structure stored at a second user-computer terminal; and updating said data structure in response to said comparison.

Brief Description of the Several Views of the Drawings

[0008] *Figure 1* illustrates a network environment, including user terminals sharing data over said network environment;

[0009] *Figure 2* shows a user terminal for sharing data shown in *Figure 1*;

[0010] *Figure 3* details hardware components of the user terminal shown in *Figure 2*, including a memory;

[0011] *Figure 4* details the contents of the memory shown in *Figure 3*;

[0012] *Figure 5* illustrates the contents of the memory of each user terminal shown in *Figures 1* to *4* for a given fluctuating bandwidth when PHBDR according to the prior art is implemented;

[0013] *Figure 6* provides a graphical representation of the Graphical User Interface displayed by the Video Display unit of any one of the user

terminals shown in *Figure 5*;

[0014] *Figure 7* illustrates updating information sent to the user terminals shown in *Figures 1 to 4* for a given fluctuating bandwidth when PHBDR according to the prior art is implemented;

5 [0015] *Figure 8* details the contents of the memory shown in *Figure 3*, including a duplication manager and duplicated objects according to the invention;

[0016] *Figure 9* summarises actions performed at a user terminal when logging onto a shared environment according to the invention;

10 [0017] *Figure 10* illustrates the contents of the memory of each user terminal shown in *Figures 1 to 3* and *Figure 8* for a given fluctuating bandwidth when PHBDR according to the invention is implemented;

[0018] *Figure 11* represents distance between duplicated objects, including an observer;

15 [0019] *Figure 12* summarises actions performed when updating duplicated objects shown in *Figures 8 to 11*;

[0020] *Figure 13* details the method of deriving distance between duplicated objects, including an observer, according to the invention;

20 [0021] *Figure 14* illustrates the updating information shown in *Figure 7* when PHBDR according to the invention is implemented;

[0022] *Figure 15* summarises actions performed according to an improved embodiment of the invention to maximise the potential number of updates shown in *Figure 8*;

25 [0023] *Figure 16* details the method of deriving distance between duplicated objects, including an observer, according to an improved embodiment of the invention;

[0024] *Figure 17* illustrates the updating information shown in *Figure 14* when PHBDR according to the improved embodiment of the invention is implemented;

[0025] *Figure 18* provides a graphical representation of the Graphical User Interface displayed by the respective Video Display Units of any two of the three user terminals shown in *Figure 11*;

Best Mode for Carrying Out the Invention

[0026] The invention will now be described by way of example only with reference to the previously identified drawings.

[0027] Applications such as simulations traditionally feature a plurality of vehicle objects comprising data, such as planes or soldiers, each of which is known to those skilled in the art as an 'entity' and is usually controlled by a user by means of a networked computer terminal. Local user input equips a local object with continuous data, such as positional data, or non-continuous data, such as event data, and said local object then interacts with other user-controlled objects within a computer-generated environment, such as a battlefield, as it is distributed to remote computer terminals by a co-ordinating server. Said simulation thus distributes each of said user-controlled object to all of the other users logged onto the network and partaking in the multi-user simulation application. An environment for connecting multiple users to whom data will be distributed is illustrated in *Figure 1*.

Figure 1

[0028] Computer terminals **101** and **102** and server **103** are respectively connected via internet service providers (ISP) **104**, **105** and **106** to the Internet **107**. The ISP's **104** to **106** in combination with computer terminals **101**, **102** and server **103** provide each individual user with a unique IP address, e-mail account and other optional internet facilities such as are commonly provided to a user with an ISP account. Provided that appropriate data transfer applications, protocols and permissions have been set up, there is provided the scope for any one of computer terminals **101** and **102** to access and receive data stored on server **103**.

[0029] A computer terminal for controlling shared objects and receiving updating data thereof within a computer-generated environment maintained over the network shown in *Figure 1* is shown in *Figure 2*.

Figure 2

[0030] A user **201**, is shown who primarily uses a computer terminal **202**, having a drive **203** for receiving CD-ROMS **204** and writing to CD-RAMS **205** and a drive **206**, for receiving high capacity magnetic disks such as zip disks **207**. According to the present invention, computer **202** may receive program instructions such as a simulation application via an appropriate CD-ROM **204** or data relating to the simulation experience may be written to a re-writable CD-RAM **205** and said data may be received from or written to a zip disk **207** by means of drive **206**. The computer-generated environment, the local objects and remote shared objects are displayed on a visual display unit **208** and manual input is received from user **201** via a

keyboard **209** and a mouse **210**. Data may also be transmitted and received over a local area network **211**, or the Internet **107** by means of modem connection **212**.

5 **[0031]** The typical components of computer terminal **202** shown in *Figure 2* are detailed in *Figure 3*.

Figure 3

10 **[0032]** A central processing unit **301** fetches and executes instructions and manipulates data. Frequently accessed instructions and data are stored in a high-speed cache memory **302**. Said central processing unit **301** is connected to a system bus **303**. System bus **303** provides connectivity with a larger main memory **304**, which requires significantly more time for the CPU to access than the cache **302**. The main memory **304** contains between sixty-
15 four and two hundred and fifty-six megabytes of dynamic random access memory. A hard disk drive (HDD) **305** provides non-volatile bulk storage of instructions and data. A graphics card **306** receives graphics data from the CPU **301**, along with graphics instructions and supplies graphical data to visual display unit **308**. The I/O device **307** or universal serial bus **308** receive
20 input commands from keyboard **209** and mouse **210**. Zip drive **206** is primarily provided for the transfer of data, such as, and CD-ROM drive **203** is provided for the loading of new executable instructions to the hard disk drive **305** and the storing of application data. A network card **309** provides connectivity to the local area network **211** and a modem **310** provides
25 connectivity to the Internet **107** via a telephone connection to the user's ISP. The equipment shown in *Figure 3* constitutes a personal computer of fairly

standard type, such as an IBM compatible PC or Apple Macintosh.

[0033] The contents of the main memory **304** shown in *Figure 3* of the user's personal computer **202** shown in *Figures 1* and *2* are detailed according to the prior art in *Figure 4*.

Figure 4

[0034] An operating system, including a basic BIOS is shown at **401**. This provides common functionality shared between all applications operating on the computer terminal **202**, such as disk drive access, file handling and window-based graphical user interfacing. An Internet browser is shown at **402**, which includes a file browser and other items, that are usually present but inactive on the user's graphical desktop. The simulation application **403** includes the program steps required by the CPU **301** to act upon vehicles objects within the computer-generated environment, the type of which comprise either local objects **404** or shared objects **405**, also known to those skilled in the art as modelled entities.

[0035] Local objects **404** are the components of user **201**'s entity which, in the example, are for instance the fixed and variable attributes of an aeroplane. Fixed attributes traditionally include the aircraft's three-dimensional model, known to those skilled in the art as 'wireframe model', the bitmapped textures applied to said wireframe model and the various weapons that can be used by said aircraft. Variable attributes include the positional data which can be expressed as the aircraft's three-dimensional position, velocity and angle of direction within the computer-generated

environment, and also whether the aircraft has fired a weapon or not. The simulation application **403** performs program steps to equip the aircraft with data inputted by user **201** by means of keyboard **209** and/or mouse **210**, i.e. modify its variable attributes in answer to the user's control decisions.

5 Simulation application **403** subsequently broadcasts the related aircraft state changes to server **103** in order to update the remote instantiations of said aircraft accordingly at every computer terminal logged onto the network, such as the Internet **107**, and partaking in the same simulation application as user **201**.

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[0036] Shared objects **405** are the variable attributes of the remote entities within the computer-generated environment which are controlled by the other users logged onto the network, such as the Internet **107**, and partaking in the same simulation application as user **201**. Simulation application **403** locally instantiates the fixed variables of said remote entities and equips said remote entities with positional and event data received and updated from the server **103** which co-ordinates the computer-generated environment. As more users partake in the simulation, i.e. evolve within the virtual battlefield by means of their respective entity, more corresponding remote entities are instantiated by each individual simulation application node and thus more shared objects require updating.

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[0037] It was previously explained that said shared objects must be updated as frequently as possible in order to sustain the immersive character, i.e. 'believable reality' portrayed by such an application, in order for user **201** to react correctly to events displayed on VDU **208** from the

simulation application **403**. Early generations of simulation applications involving multiple networked users relied on updating the shared objects **405** by a complete dataset, including fixed and variable attributes. Such early art is most inappropriate for networks with a narrow bandwidth, because every object update would require seconds as opposed to hundreds of milliseconds, resulting in a display refreshment rate of one frame per many seconds given the amount of data to broadcast and process, and thus would render the application unrealistic. Moreover, said updates would irremediably vary in frequency and contents, as in open networks such as the Internet **107**, said narrow bandwidth is known to fluctuate quite importantly and when bandwidth becomes insufficient for the amount of data to transmit, entire packets of data are lost before they arrive at each node or are delivered too late at said nodes for processing and rendering at a satisfactory frame rate. Said missing packets of data is a problem known to those skilled in the art as 'packet loss'.

[0038] According to the prior art, Position History-Based Dead Reckoning (PHBDR) is implemented in order to reduce the amount of updating information which must be circulated throughout the network to each simulation node, such that the problem posed by 'packet loss' is minimised. The contents of the respective main memories **304** of computer terminals shown in *Figures 1* to *4* for a given fluctuating bandwidth when PHBDR is implemented according to the prior art are shown in *Figure 5*.

Figure 5

[0039] In the example, computer terminal **101** is connected to the Internet **107** via ISP **104** and its user controls an aircraft **501** stored as a local object in its main memory. Computer terminal **102** is also connected to the Internet **107** via ISP **105** and its user controls an aircraft **502** stored as a local object in its main memory. Upon the computer terminal **101** logging onto the server **103** over the network **107**, its aircraft object **501** is instantiated at said server **103** as a set of fixed attributes and remote variable attributes which define a remote aircraft **503**. Similarly, upon the computer terminal **102** logging onto the server **103** over the network **107**, its aircraft object **502** is instantiated at said server **103** as a set of fixed attributes and remote variable attributes which define a remote aircraft **504**. Said remote aircraft **503** is instantiated at terminal **102** controlling local aircraft **502** and corresponding remote aircraft **504** and said remote aircraft **504** is instantiated at terminal **101** controlling local aircraft **501** and corresponding remote aircraft **503**.

[0040] Position History-Based Dead Reckoning implemented into the simulation application **403** according to the prior art extrapolates the future position, expressed as (x, y, z) co-ordinates, of the shared objects based upon a plurality of previous and recent (x, y, z) positions occupied by said remote objects within the three-dimensional computer-generated environment. Said extrapolation derives either a line axis or a curve along which a remote object is expected to move, from three or more recent three-dimensional positions sequentially occupied by the object, and improved embodiments of said PHBDR protocol are known to also derive an object's velocity and angle of direction within the computer-generated

environment. A threshold is defined by the programmer who implements said PHBDR into the simulation application **403**, such that the position of said remote object only requires updating if the error between the actual (x, y, z) position and the extrapolated positional (x, y, z) values of the corresponding local object exceed said threshold. For the purpose of simulation cohesiveness, a minimal number of updates per second is also defined by the programmer who implements said PHBDR into the simulation application **403**, traditionally of the order of five updates per second for a minimum of thirty frames displayed on VDU **208** per second.

[0041] Thus, upon the user **201** operating computer terminal **101** imparting movement or an event to aircraft **501**, the local simulation application **403** performs a program step to update the object's corresponding data stored on server **103** and thus broadcasts (**505**) a state change including the required updating data to said server **103**. Said updating data from computer terminal **101** transits via ISP **104** to ISP **106**, which in turns transmits said updating data to server **103**.

[0042] The server **103** subsequently performs a program step to update the remote aircraft **503** corresponding to the local object **501** controlled by computer terminal **101**, which is stored at all of the remote simulation application nodes currently logged onto the network it coordinates, such as the simulation application **403** running on computer terminal **102**, and thus broadcasts (**506**) said state change according to the PHBDR protocol explained thereabove. Said updating data from server **103** transits via ISP **106** to ISP **105**, which in turns transmits said updating data

to computer terminal **102**.

[0043] The position of the remote aircraft **503** stored at computer terminal **102** is extrapolated five times for displaying said aircraft over five frames and then updated with the movement or event imparted to aircraft **501** by user **201**, unless the difference between the extrapolated and actual three-dimensional co-ordinates exceeds the implemented threshold inside of five extrapolated frames and thus triggers an earlier update from server **103**. The user of computer terminal **102** is now able to make decisions regarding input with which to impart the local aircraft **502** in response to the behaviour of updated remote aircraft **503**.

[0044] A graphical representation of the graphical user interface (GUI) of simulation application **403** as displayed by the respective Video Display Units of computer terminals **101** and **102** is shown in *Figure 6*.

Figure 6

[0045] VDU **208** of computer terminal **101** displays the GUI **601** of the computer terminal's operating system **401**, within which a windowed GUI **602** of the local simulation application **403** is also displayed. Within said GUI **602**, a rendered graphical representation **603** of local aircraft **501** can be observed, as well as a rendered graphical representation **604** of remote aircraft **504**. Said rendered graphical representation **603** is displayed from a point of view situated at the back of aircraft **501**, as user **201** must be able to view the three-dimensional computer-generated environment in front of said aircraft in order to correctly decide which actions to impart the aircraft with, for

instance in order to 'fly' above a mountain ridge or 'shoot' at the remote aircraft 504.

[0046] Similarly, VDU 208 of computer terminal 102 displays the GUI 601 of the computer terminal's operating system 401, within which a windowed GUI 602 of the local simulation application 403 is also displayed. Within said GUI 602, a rendered graphical representation 605 of local aircraft 502 can be observed, as well as a rendered graphical representation 606 of remote aircraft 503. Said rendered graphical representation 605 is displayed from a point of view situated at the back of aircraft 502, as the user of computer terminal 102 must be able to view the three-dimensional computer-generated environment in front of said aircraft in order to correctly decide which actions to impart the aircraft with, for instance in order to 'fly' so as to evade fire from the remote aircraft 503 or 'shoot' at it.

[0047] Throughout the course of the simulation experience, the GUI 602 at computer terminal 101 refreshes the action displayed to user 201 based upon the actual three-dimensional position of local aircraft 501 and the extrapolation of the three-dimensional position of remote aircraft 504, and likewise at computer terminal 102, wherein the action is displayed based upon the actual three-dimensional position of local aircraft 502 and the extrapolation of the three-dimensional position of remote aircraft 503.

[0048] However, as more participants log onto server 103 and partake in the distributed simulation application, and thus more remote vehicle objects are instantiated at every participating terminal and require

updating, even PHBDR according to the prior art suffers from the problem of 'packet loss' when the amount of data corresponding to the required number of concurrent updates exceeds the available bandwidth. The situation of packet loss when PHBDR is implemented according to the prior art is graphically detailed in *Figure 7*.

Figure 7

[0049] The amplitude **701** of the total available network bandwidth is represented as a vertical axis and ranges between the minimum value of zero bit per second and the maximum value of 56,000 bits per second, the later value corresponding to the typical modem connection speed of a computer terminal connected to the Internet **107**. It is known that said maximum value, represented by continuous line **702**, fluctuates unpredictably over time, represented by horizontal axis **703**. Said fluctuation arises from the varying amount of data transmitted by the network at any point in time, known to those skilled in the art as 'network traffic', and also from key network points -such as ISP servers- logging on and off said network for reasons of maintenance or failure.

[0050] The early prior art discussed earlier relied on constantly utilising the entire available bandwidth **704** for updating remote objects. The PHBDR protocol according to the prior art relies on updating remote objects on a need-only basis, with only few updates per second required to reconcile the extrapolated position and actual position of a shared object, thereby decreasing the amount of network traffic to only the portion of bandwidth **705** required to transfer said updating data.

[0051] However, said portion of bandwidth **705** also fluctuates as more participants log onto the network and partake in the simulation application **403**. There is thus the potential for said portion **705** to rise to a maximum value **706** at a point in time where the maximum value **702** of the network bandwidth fluctuates to a value below said value **706**, thereby generating a 'packet loss' **707**. Said packet loss **707** is a portion of the data transiting within portion **705** and required to update one or a plurality of remote objects at a receiving node, and said portion of data will consequently not form part of the packet of updating data arriving at the receiving node. The respective positions of said remote objects therefore keep being extrapolated until such time as a complete packet of updating data is received, wherein their positions and also states are then abruptly and unrealistically adjusted and potentially render any local input decision redundant at said receiving node.

[0052] Faster open network connections, such as 'T3' known to those skilled in the art, are available and provide an increased amplitude **701**, but with regard to the scalability required of simulation application **403**, in order to accommodate potentially hundreds of thousands of concurrent users, the problem of packet loss remains nevertheless identical. A greater number of concurrent users is required than would be in the situation detailed in *Figure 7* in order to eventually generate the same problem.

[0053] The present invention discloses a solution to the problem affecting the known prior art by providing a computer network and a method to define and update shared objects, wherein the updating of said shared

objects is based upon the distance between the local object and the remote objects within the same computer-generated environment. Whereas the prior art implements the server-based updating of shared objects and the PHBDR protocol based upon whether an object is present within the computer-generated environment or not, the present invention does not require a server such as server 103 to arbitrate actual and extrapolated positional values and also provides an improved PHBDR protocol wherein the distance between the local object and the remote objects within the same computer-generated environment determines the frequency with which remote objects are updated. An improved embodiment of the present invention provides the distance-based PHBDR protocol with a quality factor, wherein said quality factor further determines said frequency based upon the available bandwidth at the time of sending packets of updating data.

[0054] According to the invention, the contents of the main memory 304 of the user's personal computer 101 shown in *Figure 3* are summarised in *Figure 8*.

Figure 8

[0055] An operating system, including a basic BIOS is shown at 801. This provides common functionality shared between all applications operating on the computer 101, such as disk drive access, file handling and window-based graphical user interfacing. An Internet browser is shown at 802, which includes a file browser and other items, that are usually present but inactive on the user's graphical desktop. The simulation application 803 comprises the program steps required by the CPU 301 to act upon vehicles

objects within the computer-generated environment, which are known as 'duplicated objects' according to the invention and comprise either duplicas **804** or duplicate masters **805**, and said program steps also include a duplication manager **806**.

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[0056] The duplication manager **806** is responsible for allocating the portion of main memory **304** necessary to the successful establishment of duplicated objects and for servicing said duplicated objects throughout their life-cycle. The duplication manager **806** also monitors the machines from which it receives data from remote duplicate masters **805** using keep-alive procedures. For instance, in the case of a communication failure, the duplication manager **806** ensures that only one duplica **804** will take over the responsibility of a duplicate master **805**. Similarly, in the case of a new computer terminal connecting to the network **107**, the duplication manager **806** detects said connection and informs the duplicate master **805** to take appropriate subsequent action. Finally, outside the context of a fault-induced triggering event as described above, the load-balancing task of the duplication manager **806** can also be performed automatically, the result of which is also to switch the state of a duplicate to the state of duplicate master **805** and toggle the state of the previous duplicate master **805** to the state of duplica **804**.

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[0057] The duplicated objects can be either duplicas **804** or duplicate masters **805**. They provide object duplication functionality and include dynamic elements, such as attributes and methods, with methods performing attributes processing. Upon being informed by the duplication

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manager **806** of a new computer terminal that said new computer terminal has connected to the network, the duplication manager **806** in charge of the duplicate master **805** determines whether applications running on said new computer terminal require a duplicate and, subsequently, the duplication manager **806** of said new computer terminal creates a local duplica and the duplicate master **805** provides the most recent data or object to said duplica in the main memory of said new computer terminal, so that said the duplica can operate in synchronicity with the duplicate master **805**.

[0058] A duplicate master **805** contains generic or application-specific data, which requires sharing over a network in synchronicity with its duplicas. It acts as a co-ordinator between a shared application and its duplicas, such that changes on the duplicate master **805** are propagated to its duplicas, in order to preserve system integrity. As apex co-ordinator, the duplicate master **805** is equipped with a mechanism allowing it to trigger a locally-executed method on all remote duplicas **804**, called an action.

[0059] A duplica **804** is structured with potentially the same functionality as a duplicate master **805**, but initially only maintains information for local data access and performs methods for local processing. As dependent from the duplicate master **805**, the duplica **804** is equipped with a mechanism allowing it to trigger a locally-executed method on the duplicate master **805**, called reversed action. For instance, should a duplica **804** require a change in the data it contains in answer to an application command, it will trigger a reversed action and obtain updated information from the duplicate master **805**.

[0060] Actions performed at a user terminal according to the invention when logging onto a computer-generated environment are summarised in *Figure 9*.

5 **Figure 9**

[0061] Upon activation of a computer terminal **101** at step **901**, the instructions necessary for the simulation application **803** and duplication manager **806** to carry out their program steps may need to be loaded from an external medium, such as CD ROM **204**, at step **902**.

10 [0062] As the simulation application **803** and the duplication manager **806** within said simulation application **803** are launched locally, the local entity controlled by the user **201** is instantiated in main memory **304** as a duplicate master **805**. Computer terminal **101** then connects to the network **107** in order to join in the computer-generated environment shared between other networked-connected users.

15 [0063] Upon establishing the network connection, said duplicate master **805** is simultaneously detected by all remote duplication managers **806** currently connected to the same network group as said computer terminal **101** at step **904**, for instance the respective duplication managers **806** of computer terminal **102** and server **103** which, in the example according to the invention, is now computer terminal **103**. Each remote duplicate master **805** comprising data and methods then creates a local duplica **804** in the main memory of the local user terminal **101** from its
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25 current set of information available at step **905**. The simulation application

803 at terminal **101** can now access data in the respective duplicas **804** of the entity controlled by said terminals **102** and **103** and process said data locally via the instructions associated with said duplicas.

5 **[0064]** The duplicate master **905** ensures that its respective duplicas **804** are regularly updated in order to achieve and maintain data consistency at step **906**.

10 **[0065]** As more users join in said computer-generated environment, the main memory **304** of user terminal **101** stores the duplicate master **805** and an increasing plurality of duplicas **804**, such that the total processing activity load placed upon the CPU may eventually exceed a delimited amount necessary for the fluid operation of the simulation application **803**, including the duplication manager **806**, stored in its memory. A typical
15 instance where the user can ascertain whether they need to perform a load balancing instruction at step **907**, in order to alleviate said processing load placed upon said CPU, occurs when the frame update rate of simulation application **803** decreases below a threshold value of typically fifteen frames per second, which represents the frame update rate required to
20 portray fluid motion of entities.

25 **[0066]** In this instance, the duplicate master **805** therefore switches the state of a remote duplica **804** to the state of duplicate master at step **908**, in effect delegating its master status to said remote duplica, in order to balance the resource load generated by the duplication manager **806** and duplicate master **805** between the local and remote sets of user terminal

CPU resources. Thus, the main memory **304** of user terminal **101** stores the duplicate master **805** and an increasing plurality of duplicas **804**, the state of any of which can also be switched to the state of duplicate master **805** according to load balancing instructions performed remotely. Said state change is transparent, i.e. the user **201** remains unaware of the state change of the duplicas stored in the main memory of user terminal **101**.

[0067] Alternatively, if the main memory of the user terminal **101** which stores the duplicate master **905** becomes unavailable on the network **107**, i.e. if the keep-alive procedures are breached by loss of connectivity, then the duplication manager performs fault recovery at step **907**. Remote duplication managers **806** elect only one duplica **804** to become the duplicate master **805** and then switch the state of this remote duplica to the state of a duplicate master, ensuring that a single duplica amongst all identical duplicas present on a network takes over the responsibility of sharing and updating the data. As at step **908**, the user remains unaware of the state change of the duplica stored in the main memory of the user terminal they operate.

[0068] The contents of the respective main memories **304** of each computer terminals show in *Figures 1* to *3* for a given fluctuating bandwidth when PHBDR is implemented according to the invention are shown in *Figure 10*.

Figure 10

[0069] Whereas a server **103** was necessary to implement PHBDR according to the prior art and distribute shared objects in terms of variable data updates, the present invention dispenses with said server and, as previously explained, server **103** is now to be considered as any other computer terminal connected to network **107**. In the example, computer terminal **101** is connected to the Internet **107** via ISP **104** and its user controls an aircraft **1001**. According to the invention, said aircraft **1001** is initiated and stored as a duplicate master **805** according to steps **901** to **903**. Computer terminals **102** and **103** are also connected to the Internet **107** via ISP **105** and **106** respectively, and their respective users each control an aircraft **1002**, **1003** stored as stored as a duplicate master **805** in their respective main memories.

[0070] If computer terminals **102** and **103** are logged onto the network **107** before computer terminal **101**, upon the computer terminal **101** logging onto said network **107**, its aircraft object **1001** is instantiated as a remote shared object **1004** at each computer terminal **102** and **103** wherein it is stored as a duplica **804**, according to steps **904** and **905**. Similarly, if computer terminals **101** and **103** are logged onto the network **107** before computer terminal **102**, upon the computer terminal **102** logging onto the network **107**, its aircraft object **1002** is instantiated as a remote shared object **1005** at each computer terminal **102** and **103** wherein it is stored as a duplica **804**, and likewise for aircraft object **1003** of computer terminal **103** instantiated as a remote shared object **1006** if computer terminals **101** and **102** are logged onto the network **107** before computer terminal **103**.

[0071] A duplicate master stored in the main memory of any one of said computer terminals connected to network **107** updates its duplicas stored at the other computer terminals connected to said network, according to step **906**. Thus, duplicate master **805** at computer terminal **101**, i.e. aircraft object **1001**, updates (1007) the duplicas **804**, i.e. aircraft objects **1004** stored at computer terminals **102** and **103**. Likewise, duplicate master **805** at computer terminal **102**, i.e. aircraft object **1002**, updates (1008) the duplicas **804**, i.e. aircraft objects **1005** stored at computer terminals **101** and **103** and duplicate master **805** at computer terminal **103**, i.e. aircraft object **1003**, updates (1009) the duplicas **804**, i.e. aircraft objects **1006** stored at computer terminals **101** and **102**.

[0072] In the case of many thousands of concurrent users of simulation application **803** connected to network **107**, all of whom interacting within the same computer-generated environment, the above updates would involve thousands of duplicate masters updating many more thousands of duplicas and a solution must therefore be implemented in order to further reduce the amount of network traffic generated by said updating activity. The present invention implements the calculation of the distance between shared objects, i.e. between duplicate masters **805** and duplicas **804**, within said PHDR protocol in order to determine the degree of relevance according to which shared objects should be updated at every local simulation application **803**. Said distance between shared objects is illustrated in *Figure 11*.

Figure 11

[0073] Aircraft 1001 of computer terminal 101 is shown, along with aircraft 1005 duplicated from aircraft 1002 of computer terminal 102, and aircraft 1006 duplicated from aircraft 1003 of computer terminal 103. The field of vision 1101 represents the tri-dimensional field of vision afforded by means of GUI 602 to the user 201 of computer terminal 101 when engaging in the simulation application 803. Said field of vision, or point-of-view, is the visible portion of the entire computer-generated environment within which user 201 controls aircraft 1001 and, as said computer-generated environment is three-dimensional, every shared object is equipped with three-dimensional width, height and depth (x, y, z) co-ordinates. Aircraft 1001 is thus equipped with (x, y, z) co-ordinates 1102, aircraft 1005 is equipped with (x, y, z) co-ordinates 1103 and aircraft 1006 is equipped with (x, y, z) co-ordinates 1104.

[0074] Traditionally, aircraft 1001 of user 201 is referred to as the 'observer', as it is the origin of the field 1101 at computer terminal 101. However, aircraft 1002 at computer terminal 102 is also referred to as the 'observer', as it is the origin of a field of view similar to field 1101 which represents the tri-dimensional field of vision afforded by means of GUI 602 to the user of computer terminal 102 when engaging in the simulation application 803. As it was previously explained that the aircraft controlled at a computer terminal is the duplicate master of said aircraft duplicates over the entire network 107, said duplicate master is an observer and duplicates are observed. More generally, according to the invention, the observer is the object which defines the origin of the field of vision 1101 from which the three-dimensional computer-generated environment is observed and,

according to refinements known those skilled in the art implemented in the rules of simulation application **803**, user **201** may at any time 'switch' said origin from his aircraft **1001** to any of the objects present within said three-dimensional computer-generated environment, including for instance aircraft **1005**, thereby making a duplica the observer.

[0075] In the example, the respective three-dimensional co-ordinates **1103**, **1104** of aircrafts **1005** and **1006** places said aircrafts in the computer-generated environment in front of aircraft **1001** and said aircrafts are visible to user **201**. A distance **1105** therefore separates aircraft **1001** from aircraft **1005** and a distance **1106** therefore separates aircraft **1001** from aircraft **1006**. Thus, a distance separates duplicate master **805**, which is the observer, from the duplicas **804**, which are observed.

[0076] Actions performed by the simulation application **803** when a duplicate master updates a duplica, including calculating a distance shown in *Figure 11*, are shown in *Figure 12*, and *Figure 13* details the computations for deriving said distance between duplicated objects, including an observer, according to the invention.

[0077] At step **1201**, the current extrapolation error is computed as the difference between the current value and the extrapolated value of a dataset, i.e. (x, y, z) co-ordinates of a duplica. The error is calculated according to the equation **1301** shown in *Figure 13*, wherein the xi values are the values of different variables contained within the same dataset, and the xi' values are the extrapolated value of said variables. According to the invention, each of

the variables of a dataset should have a similar range of values, such that no variable predominantly influences the result of the computation.

[0078] At step **1202**, the distance between the observer **1001** and the
5 duplica **1004** or **1005** observed is computed much in the same manner as
the extrapolation error. Said distance is computed as the difference between
the value of a dataset of the duplica and the value of a dataset of the
observer, i.e. their respective (x, y, z) co-ordinates. The distance is calculated
10 according to the equation **1302** shown in *Figure 13*, wherein the x_i values are
the values of different variables contained within the duplica dataset, and the
 x_i' values are the value of different variables contained within the observer
dataset. According to the invention, each of the variables of a dataset should
have a similar range of values, such that no variable predominantly
15 influences the result of the computation.

[0079] The above distance illustrates a symmetrical relationship but it
will be apparent to those skilled in the art that, more generally, the above
distance embodies the relevance according to which the observer requires
the observed duplicas to be updated. Variations of step **1202** to
20 accommodate other types of relationship known to those skilled in the art are
also claimed by the present invention. Said other types of relationship include
for instance a 'line-of-sight' relationship, wherein the observer cannot 'see' a
very close duplica because said duplica is placed behind an obstruction or
even the observer itself: step **1202** thus also artificially increases the
25 computed distance between the observer and said duplica as updates of said
duplica are not required.

[0080] At step 1203, the error tolerance is computed as a function of the distance between the observer and the duplica. The error tolerance is calculated according to the equation 1303 shown in Figure 13, wherein the *dConstant* variable defines a constant value for the error tolerance if no default tolerance is implemented in the application, the *dLinear* variable defines a ratio when a linear relationship between the error tolerance and the distance is implemented, and the *dQuadratic* variable defines a ratio when a quadratic relationship between the error tolerance and the distance is implemented, i.e. when there is no linear dependence. The Z variable is the distance computed at step 1202 according to the equation 1302. It can therefore be said that the tolerated error changes according to the computed value of the distance between the observer and shared objects.

[0081] According to the present invention, the precision of the extrapolation adjusts dynamically based upon the computed distance and said function of the distance between the observer and a duplica can be set such that the extrapolation error decreases as the distance between the observer and a duplica decreases: as a shared object moves closer to the observer, the error decreases and the object's dataset will be updated more frequently so that the duplica's (x, y, z) co-ordinates within the computer-generated environment are updated more frequently. Typically, said function of the distance between the observer and a duplica according to the invention is set such that a larger error is tolerated for shared objects rendered at a large distance from the observer and, inversely, a smaller error is tolerated for shared objects rendered closer to the observer.

[0082] At step **1204**, the extrapolation error is compared with the error tolerance. If the extrapolation error is smaller than the error tolerance, then control is returned to step **1201** as the duplicate master **805** does not need to update its duplica **804**, since the extrapolated value of said duplica's dataset is deemed acceptable for rendering. If the extrapolation error is greater than the error tolerance, however, then at step **1206** the duplicate master **805** updates its duplica **804** and transmits actual data, in the example (x, y, z) positional data, with which to equip said duplica. According to the invention, as the distance between the observer on each of networked computer terminals **101** to **103** and the shared objects at each of said networked computer terminals **101** to **103** can be different, updates may be sent at different frequencies. In the example, and referring back to *Figure 10*, it can be observed that aircraft **1006** is further away from aircraft **1001** than aircraft **1005**. Thus, the duplicate master **805** of aircraft **1005** at computer terminal **102** updates the duplica **804** of said aircraft **1005** at computer terminal **101** at a higher frequency than the duplicate master **805** of aircraft **1006** at computer terminal **103** updates the duplica **804** of said aircraft **1006** at said computer terminal **101**.

[0083] Similarly, it can be observed that aircraft **1006** of computer terminal **103** is closer to aircraft **1005** of computer terminal **102** than to aircraft **1001** of computer terminal **101**. Thus, the duplicate master **805** of aircraft **1006** at computer terminal **103** updates the duplica **804** of said aircraft **1006** at computer terminal **102** at a higher frequency than it updates the duplica **804** of said aircraft **1006** at computer terminal **101**.

[0084] According to the invention, as more participants log onto network 107 and partake in the distributed simulation application 803, and thus more duplicate masters 805 and duplicas 804 are instantiated at every participating terminal and require updating, PHBDR according to the invention solves the problem of 'packet loss' as the amount of data corresponding to the required number of concurrent updates is dynamically minimised by means of the computation of the distance and thus constantly remains within the available bandwidth. The updating information shown in *Figure 7* when PHBDR according to the invention is implemented is graphically detailed in *Figure 14*.

Figure 14

[0085] As previously described, the amplitude 701 of the total available network bandwidth ranges between the minimum value of zero bit per second and the maximum value of 56,000 bits per second, the later value corresponding to the typical modem connection speed of a computer terminal connected to the Internet 107. Said maximum value, represented by continuous line 702, fluctuates unpredictably over time, represented by horizontal axis 703. Said fluctuation arises from 'network traffic', and also from key network points logging on and off said network for reasons of maintenance or failure.

[0086] It was previously explained that the PHBDR protocol according to the prior art relies on updating remote objects on a need-only basis, with only few updates per second required to reconcile the extrapolated position and actual position of a shared object, thereby

decreasing the amount of network traffic to only the portion of bandwidth
705 required to transfer said updating data. However, as more users take
part in simulation application 403 and therefore more shared objects require
updates, the amount of data corresponding to said mounting number of
5 updates increases to the extent of potentially using the entire available
bandwidth and thus there remains the potential for generating a 'packet
loss' 707. The respective positions of said shared objects therefore keep
being extrapolated until such time as a complete packet of updating data is
received, wherein their positions and also states are then abruptly and
10 unrealistically adjusted and potentially render any local input decision
redundant at said receiving node.

[0087] However, the PHBDR protocol according to the invention
relies on updating remote objects on a need-only basis, wherein said need
15 is assessed by means of the distance between the observer and observed
shared objects rather than as a constant function. Shared objects within the
computer-generated environment which the user 201 does not need to take
into account when implementing entity control decisions are therefore
barely updated at all, because such shared objects are too distant to the
20 user's entity to be of importance, until such time as said user's entity
becomes closer to said distant shared objects. The amount of data required
in order to update close and distant shared objects at user 201's computer
terminal is therefore constantly minimal, as said amount of data only
includes updates pertaining to close-by duplicas rather than every duplica
25 within the total computer-generated environment.

[0088] The maximum portion of bandwidth **1401** required to transfer said updating data is thus permanently lower than the portion **706** according to the prior art, as less updating data is transmitted. As more users take part in simulation application **803** and therefore more duplicas **804** require updating, the amount of bandwidth **1402** used to transmit said mounting number of updates remains minimal at all times. At each computer terminal, regardless of their number, the respective positions of said duplicas therefore keep being extrapolated and updated according to the PHBDR protocol of the present invention, wherein their positions and states are realistically adjusted without arbitrary positional updates arising from packet loss.

[0089] As the PHBDR protocol according to the invention minimises the amount of data transmitted to update the variable attributes of shared objects such that important bandwidth fluctuations do not generate any disruption of the updating action, a preferred embodiment of the present invention allows the computed error tolerance **1203** to dynamically adjust in function of the available bandwidth at any one time. Actions performed at step **906** according to a preferred embodiment of the invention in order to maximise the potential number of updates by the simulation application **803** are shown in *Figure 15*, and *Figure 16* details the computation for deriving the error tolerance according to said preferred embodiment of the present invention.

Figures 15 and 16

[0090] It was previously explained that the error tolerance computed at step 1203 determines the frequency of updates when compared with the extrapolation error computed at step 1201. As the distance between the observer and the duplica decreases, a lower error tolerance 1203 increases the number of updates, thereby resulting in a better-updated duplica 804 which is more representative of the control decisions implemented by the computer terminal user who controls its respective duplicate master 805. Alternatively, as the distance between the observer and the duplica increases, a lower a higher error tolerance 1203 decreases the number of updates of said duplica 804, as the control decisions implemented by the computer terminal user who controls its respective duplicate master 805 are becoming less relevant to the computer terminal user who controls the observer.

[0091] According to a preferred embodiment of the present invention, the extrapolation error is computed at step 1201 according to the equation 1301 and the distance between the observer 1001 and the observed observed duplica 1004 or 1005 is computed at step 1202 according to the equation 1302. At step 1501, a question is asked as to whether any spare bandwidth is available for use. If answered positively, a quality factor 1601 is implemented in the computation of the error tolerance and increased by a pre-determined increment at step 1502, such that the value of the error tolerance computed at step 1503 according to the equation 1602 is decreased by a ratio equal to the distance computed at step 1202 divided by said incremented quality factor 1601.

[0092] If the question asked at step 1501 is answered negatively, however, a quality factor 1601 is implemented in the computation of the error tolerance and decreased by a pre-determined increment at step 1502, such that the value of the error tolerance computed at step 1503 according to the equation 1602 is increased by a ratio equal to the distance computed at step 1202 divided by said incremented quality factor 1601. The extrapolation error is then compared with the error tolerance according to step 1204. The effect of the quality factor 1601 is thus to dynamically maximise the potential number of updates in relation with the available bandwidth, without however incurring the problem of packet loss, by means of maximising or minimising the error tolerance and thus dynamically adjusting the comparison of step 1204.

[0093] The updating information shown in *Figure 14* when PHBDR according to an improved embodiment of the present invention is implemented is graphically detailed in *Figure 17*.

Figure 17

[0094] As previously described, the amplitude 701 of the total available network bandwidth ranges between the minimum value of zero bit per second and the maximum value of 56,000 bits per second, the later value corresponding to the typical modem connection speed of a computer terminal connected to the Internet 107. Said maximum value, represented by continuous line 702, fluctuates unpredictably over time, represented by horizontal axis 703. Said fluctuation arises from 'network traffic', and also from key network points logging on and off said network for reasons of

maintenance or failure.

[0095] It was previously explained that the maximum portion of bandwidth 1401 required to transfer updating data is permanently lower than the portion 706 according to the PHBDR protocol of the present invention, as less updating data is transmitted. As more users take part in simulation application 803 and therefore more duplicas 804 require updating, the amount of bandwidth 1402 used to transmit said mounting number of updates remains minimal at all times.

[0096] According to a preferred embodiment of the present invention, however, unused bandwidth 1701 is determined as available at step 1501 and, following the incrementing of quality factor 1601 at step 1502 and error tolerance computation at step 1503, the portion of bandwidth 1401 required to transfer updating data is incrementally maximised to a portion of bandwidth 1702 marginally smaller than the maximum available bandwidth 702, wherein duplicas 804 are more frequently updated and thus rendered as accurately as possible. As said maximum available bandwidth 702 fluctuates over time, the total amount of bandwidth 1703 used by simulation application 803 in order for local duplicate master 805 to update remote duplicas 804 fluctuates in kind. Decreasing bandwidth 702 is eventually determined at step 1501 and, following the inverse incrementing of quality factor 1601 at step 1504 and error tolerance computation at step 1505, the portion of bandwidth required to transfer updating data is incrementally decreased to a portion of bandwidth 1704, wherein duplicas 804 are less frequently updated but still rendered as accurately as possible, as they are

no less frequently updated than according to the portion of bandwidth **1401**.

[0097] The graphical user interface (GUI) of simulation application **803** displayed by the respective Video Display Units of computer terminals **101** and **103** are shown in *Figure 18* according to the preferred embodiment of the present invention.

Figure 18

[0098] VDU **208** of computer terminal **101** displays the GUI **1801** of the computer terminal's operating system **801**, within which a windowed GUI **1802** of the local simulation application **803** is also displayed. Within said GUI **1802**, a rendered graphical representation **1803** of local aircraft **1001** can be observed, as well as rendered graphical representations **1804** and **1805** of remote aircrafts **1005** and **1006** respectively. Said rendered graphical representation **1803** is displayed from a point of view situated at the back of aircraft **1001**, which is the origin of the field of view **1101**, as the user of computer terminal **101** must be able to view the three-dimensional computer-generated environment in front of said aircraft in order to correctly decide which actions to impart the aircraft with, for instance in order to 'fly' above a mountain ridge or 'shoot' at the remote aircrafts **1005** and **1006**.

[0099] Similarly, VDU **208** of computer terminal **103** displays the GUI **1801** of the computer terminal's operating system **801**, within which a windowed GUI **1802** of the local simulation application **803** is also displayed. Within said GUI **1802**, a rendered graphical representation **1806** of local aircraft **1003** can be observed, as well as rendered graphical representations

1807 and 1808 of remote aircrafts 1005 and 1001 respectively. Said rendered graphical representation 1806 is displayed from a point of view situated at the back of aircraft 1003, as the user of computer terminal 102 must be able to view the three-dimensional computer-generated environment in front of said aircraft in order to correctly decide which actions to impart the aircraft with, for instance in order to 'fly' so as to evade fire from the remote aircraft 1001 or 'shoot' at it.

[0100] Throughout the course of the simulation experience, the GUI 1802 at computer terminal 101 refreshes the action displayed to its user based upon the actual three-dimensional position of local object 1001 rendered as aircraft 1803 and the extrapolation of the respective three-dimensional positions of remote shared objects 1005 and 1006, respectively rendered as graphical representations 1804 and 1805. As local object 1001 is the duplicate master 805 of all the aircrafts 1004, i.e. duplicas 804, throughout the network, said duplicate master 805 updates remote aircraft 1004 at computer terminal 102 and remote aircraft 1004 at computer terminal 103 according to the PHBDR protocol of the present invention, such that graphical representation 1807 at computer terminal 102 is accurately rendered within the three-dimensional computer-generated environment, and likewise at computer terminal 103. As it can be observed that the rendered graphical representation 1803 of aircraft 1001 is closer to the graphical representation 1804 of remote aircraft 1005 than it is from the graphical representation 1805 of remote aircraft 1006, said duplicate master 805 updates aircraft 1004 at computer terminal 102 more frequently than it updates aircraft 1004 at computer terminal 103.

[0101] Likewise at computer terminal **103**, where local object **1003** is the duplicate master **805** of all the aircrafts **1006**, i.e. duplicas **804**, throughout the network, it can be observed that the rendered graphical representation **1806** of local aircraft **1003** is closer to the graphical representation **1807** of remote aircraft **1005** than it is from the graphical representation **1808** of remote aircraft **1001**, said duplicate master **805** updates aircraft **1006** at computer terminal **102** more frequently than it updates aircraft **1006** at computer terminal **101**.

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